Validation of a Fully Anechoic Chamber

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Abstract—This paper describes a technique to characterize the performance of a Fully Anechoic Chamber (FAC) from 500 MHz to 3 GHz based on S-Parameter analysis with antennas and a Vector Network Analyzer (VNA). The measurements have been performed by placing one antenna inside the chamber and performing S₂₁ reflection analyses in the frequency domain. Via Inverse Fast Fourier Transformation (IFFT) the reflections in the time domain have been analyzed. Also, experiments where S₂₁ transmission loss is measured by putting 2 antennas at different locations have been performed. One antenna is omnidirectional while the other is directional and measurements have been performed in the frequency domain using the VNA. The results are transformed to time domain using the IFFT and time gating is applied to identify the direct and reflected signals, resulting in the so-called site-Voltage Standing Wave Ratio (sVSWR). This sVSWR method enables the analysis of the reflected wave, or imperfection of the chamber. The measurement results show that the chamber has good performance.

Keywords—anechoic chamber, antenna, S-parameter, s- VSWR, reflection coefficient, time domain reflectometry

I. INTRODUCTION

Anechoic chambers can be roughly divided into 2 types: Electromagnetic Compatibility (EMC) chambers for Electromagnetic Interference (EMI) measurements, and (microwave or) Radio Frequency (RF) chambers intended for antenna measurements. The latter anechoic chamber is usually equipped with absorbers on all sides of the chamber, the ceiling as well as on the floor. While for EMC, the chamber can be fully anechoic, or semi-anechoic. Then the floor is not covered by absorbers. There are several approaches for evaluation of both types of chambers, as explained in the [2 - 7]. The standard for EMC chambers [1] describes some techniques to validate EMC tests sites. As EMC measurements have conventionally been performed on Open Area Test Sites (OATS), the standard also assume a semi-anechoic chamber, which should replicate an OATS. The Normalized Site Attenuation (NSA) method is usually used for site validation below 1 GHz, while site Voltage Standing Wave Ratio (sVSWR) is recommended above 1 GHz. The Site Reference method is also mentioned as a method for alternative test sites. The time domain method to obtain s-VSWR was proposed in [2,3]. It has some advantages compared to the CISPR method [1], e.g.: faster, less errors, and it solve under-sampling issues [3]. Other papers explain methods to characterize the quite zone and the reflectivity of the chambers [4-7]. Others research were done using an ultra-wideband measurement system to verify

EMC chamber for compliance testing [8] and comparison of time domain method with field uniformity method for retrofit EMC facility [9]. While EMC test sites can be validated using the techniques described above, no standard or a widely accepted test technique is available for fully anechoic chambers which are often used for RF measurements.

The methods described above for EMC sites result in good and very accurate data, especially for full compliance testing. For a laboratory which has a small anechoic chamber for research as the main purpose, it does not need validation like a standardized anechoic chamber. However validation is still needed to quantify the performance of the chamber and give confidence for other researchers and students who want to use the chamber for research purposes. This background is the motivation for characterizing a chamber with alternative techniques, S-parameter and time domain evaluations to obtain s-VSWR of the chamber, which serves as a good estimate of chamber performance.

II. THEORETICAL BACKGROUND

A. Reflection coefficient (ρ) and return loss (S₁₁)

Return loss or S₁₁ of an antenna is defined as the ratio between the reflected and the incident wave at the antenna port. It gives information on how much power is actually transmitted by the antenna and/or how efficient is the antenna. The reflection coefficient or return loss has direct correlation with impedance matching and VSWR:

$$\rho = \frac{V^-}{V^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

and VSWR

$$\frac{1 + \rho}{1 - \rho} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$ (1)

But viewed from another perspective, when the antenna is put in a multipath environment, a different aspect is revealed. The S₁₁ is then due to the reflection path from the environment. As in [6] we can model the multiple reflections from the antenna through free space and the load.

Figure 1, shows the model of the reflection and the test setup is shown in Figure 2. The expression of this condition can be written as

$$\Gamma = \frac{\Gamma_1 + \Gamma_3 e^{-j2\beta R e^{-2\alpha R}}}{1 + \Gamma_1 + \Gamma_3 e^{-j2\beta R e^{-2\alpha R}}}$$ (2)

Γ is the reflection coefficient, α is attenuation due to free space propagation, and β is the propagation constant.
B. Transmission loss coefficient ($S_{21}$)

The transmission loss coefficient $S_{21}$ can be determined by using a vector network analyser (VNA) instruments. The test setup can be seen in Figure 3. Two antennas are used in the setup. A continuous wave signal is generated and swept over the frequency range of interest into one antenna while the other is only receiving. As expressed in [2], transmission can be formulated by:

$$E = E_D + \sum_{i=1}^{N} E_{R(i)}$$  \hspace{1cm} (3)

where $E$ is the received signal. $E_D$ is the direct path signal, $E_{R(i)}$ is the $i^{th}$ reflected signal and $N$ is total number of reflections from the site. Assume only 1 reflection has occurred, so the s-VSWR ($S$) of the site becomes:

$$S = \frac{E_{\text{max}}}{E_{\text{min}}} = \frac{E_D + E_R}{E_D - E_R} = \frac{1 + E_R/E_D}{1 - E_R/E_D}$$  \hspace{1cm} (4)

We can substitute $E_R/E_D = E_{\text{relative}}$, and obtain:

$$E_{\text{relative}} = \frac{1-S}{1+S}$$  \hspace{1cm} (5)

$E_{\text{relative}}$ is a measure for the reflection of the site and by measuring the $S_{21}$ we can determine how large the reflected waves are relative to the direct wave [2]. In ideal conditions with no reflection, $E_{\text{relative}} = 0$ and $S = 1$. With this approach we can derive $E_{\text{relative}}$ and $S$ of the chamber through the $S_{21}$ between the two antennas used. As stated in [1], the required $S$ is 1.76 or 6 dB which is equivalent to a site error of 2.23 dB, and calculated as follow:

$$\text{Site error} = \sqrt{10^{(S/20)^2}} + 1$$  \hspace{1cm} (6)

while in the time domain the site error is defined as:

$$\text{Site error} = 20 \log_{10}(10^{(\text{TDR data}/20)} + 1)$$  \hspace{1cm} (7)

where TDR is Time Domain Reflected signal.

III. TEST METHOD

The measurement described here is based on 2 methods which are $S_{11}$ reflection loss and $S_{21}$ transmission loss.

A. $S_{11}$ measurement.

The $S_{11}$ measurement is performed in two different setups. First we placed one antenna (horn) in 5 different positions inside the chamber with every positions having 4 different directions. In the second series of setups, 1 antenna is used and a corner reflector is placed at different distances in front of the antenna. This is performed in order to acquire reflection from the reflector and compare this with the chamber environment obtained in the first measurement. The antenna inside the chamber is as shown in Figure 2. First data are collected in the frequency domain for both methods. For first method, via an Inverse Fast Fourier Transformation (IFFT), the response in time domain is obtained. This enables a better separation of the reflection coming before and after the antenna port mismatch. The next step is putting a metal reflector plate in front of the antenna at 1m, 2m, and then very close to the wall of the chamber. The response $S_{11}$ from the antenna is then recorded in the frequency domain for every reflection from the reflector. From these analysis we could see the different magnitudes in the frequency band from 500 MHz to 3 GHz.

B. $S_{21}$ measurement

The $S_{21}$ measurements have been performed as well to quantify imperfections of the chamber. Two antennas were placed in the room, one is an omni-directional antenna (discone) and the other one is a horn antenna which has a directional pattern and a linear polarization. The measurement was performed at a 1.5 meter distance between the antennas, with the antennas only pointing to each other face to face. One antenna was moved along a circular trajectory to 3 different positions while the other antenna stayed fixed. The circular diameter is 1 m in the corner of the chamber to get a far field measurement. The set up can be seen in the Figure 3.
The result is then calculated by equation (4) and the ratio between the reflected and direct waves of the chamber is obtained.

IV. RESULT AND DISCUSSION

A. S_11 measurement result

The measurement results are describe below. The S_11 measurement results inside the chamber are shown in Figure 4. This is the average of S_11 for the 5 positions inside the chamber with 20 data points.

![Figure 4](image1)

Figure 4. S_11 for the antenna inside the chamber at 5 different positions.

These results it shows that S_11 antenna almost doesn’t change when putting it at different positions inside the chamber. Also it is very difficult to find differences between them. This means that the absorbers have very good performance and almost nothing reflected.

Further analysis is made with the time domain transformation. Frequency domain data are transferred to the time domain through the IFFT method in Matlab. Figure 5 shows the IFFT response of S_11 inside the chamber. The first and the second reflection are likely to be the connector between cables, and the peak is the mismatch or reflection from the antenna in the port. After the peak, there are only some small reflections are from the environment.

![Figure 5](image2)

Figure 5. Time domain graph of S11 the antenna at 5 different positions.

If we look in detail, the reflections are very similar and almost not different at all, suggesting that the absorbers are functioning very well.

Figure 6 shows the average of the S_11 measurements of the antenna and S_11 measurement when the corner reflector is put in front of the antenna at distance of 1m, 2m, and close to the absorber or wall. From these two results, it seems that the absorber has good reflectivity. Apparently this method can be used only if the antenna has a high reflection coefficient, if the reflection coming from the absorbers on the chamber walls is very low.

S_21 measurements have been performed inside the chamber to obtain the performance of the chamber. As can be seen in Figures 7 and 8, S_21 of the chamber is plotted for the vertical and horizontal polarizations in 4 different positions. Raw data in frequency domain and then the IFFT is applied to get time domain data for S21 data. In the time domain we see clearly the direct wave and reflected wave which comes from the walls, because the direct wave / line of sight (LOS) will come first at the receiving antenna.

![Figure 6](image3)

Figure 6. S_11 for the antenna with corner reflector inside chamber.

From both of the graphs Figure 7 and Figure 8 – we also see the attenuation or reflectivity level of the environment from the gap between the first peak with later delay peaks, it’s approximately 30 – 35 dB. Of course it will depend on the
system, especially for the antenna being used, but this estimation could be beneficial for others as a reference when using the chamber later.

If the chamber had perfect walls, floor, and ceiling, it should have similar polarization patterns in the vertical as well as the horizontal polarizations.

**CONCLUSION**

Standards for the evaluation of EMI chambers have been developed in the last decades. EMI standards are conventionally referring to Open Area Test Sites. Full anechoic chambers are often used for antenna and propagation measurements, and no standard validation technique is available. The sVSWR technique as described by EMC standards has been here applied to a full anechoic chamber. S11 measurements are highly influenced by reflections of other elements than the absorbers. S21 measurements give a higher confidence for the test results, but these are much more elaborate and time consuming, and are depend on the type of antenna.

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